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POSITION OF SUN AND MAGNETIC VECTOR FOR THREE LAUNCH SITES

(Wallops Island, White Sands,
and Fort Churchill)

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LLOYD T. DAVIS

JUNE 1970



GODDARD SPACE FLIGHT CENTER
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ABSTRACT

This report consists of a series of graphs whose purpose is to indicate the azimuth and elevation of the sun for any day in the year, for any time of day, at Wallops Island Range, the Churchill Research Range, or the White Sands Missile Range. An indication is also made of the azimuth and elevation of the geomagnetic vector at each of the launch sites. The report includes instructions for use of the graphs, and a section explaining the origin and the computation of the coordinates for the graphs.

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POSITION OF SUN AND MAGNETIC VECTOR FOR THREE LAUNCH SITES (Wallops Island, White Sands, and Fort Churchill)

INTRODUCTION

One of the documentation requirements of many rocket-borne experiments is that of recording the vehicle attitude at the time an observation is made. Data from the solar sensor and the magnetometer, probably the two most widely used aspect sensors in the sounding rocket field, must be used together with the knowledge of the position of the sun and magnetic vector in determining the attitude of sounding rockets.

The purpose of this document is to provide sufficient information so that a user of sounding rocketry will be able to launch the vehicle at a desirable time of day, as the time affects the direction of the sun in relation to the direction of launch.

FORMAT OF SOLAR DIRECTION DATA

Solar direction data are plotted in graphs, each containing a family of curves showing the direction or location of the sun as a function of the launch site, as well as the day of the year, and the time of day.

HOW THE GRAPHS ARE CONSTRUCTED

The curves are plotted according to a coordinate system in which the abscissas are in azimuth degrees, and the ordinates are in degrees of elevation with reference to the horizon. Each curve represents the apparent path taken by the sun on one particular day of the year. There are 18 curves for one year, with 20-day intervals between the days represented by adjacent curves. Two graphs are made for each site: one for January through June, the other for July through December.

Curves for each of the selected days are generated by plotting points at one-hour intervals over a 24-hour period on a scale that places 180 degrees azimuth, or south, at the center of the horizontal scale, and zero degrees of elevation, or horizontal, at the center of the vertical scale. Then, all of the hourly points representing a given day are connected by a curve. After all of the curves for a given graph have been drawn in a similar manner, all of the points representing each hour are connected by a curve. Each of the day curves is labeled according to the day for which that curve is valid. Each curve representing the hour is also identified.

On each graph, another point is plotted to show the azimuth and elevation of the magnetic vector at the rocket range for which the graph is valid. The completed graphs are shown in Appendix Figures A-1 through A-6.

HOW TO USE THE GRAPHS

To find the direction of the sun on one of the days for which a curve is plotted, at an integral hour point, find the coordinates of the encircled point. If the desired time includes a fraction of an hour, move a proportional distance along the line connecting two hour-points and read the coordinates of the point thus located, on the horizontal and on the vertical scales of the graph.

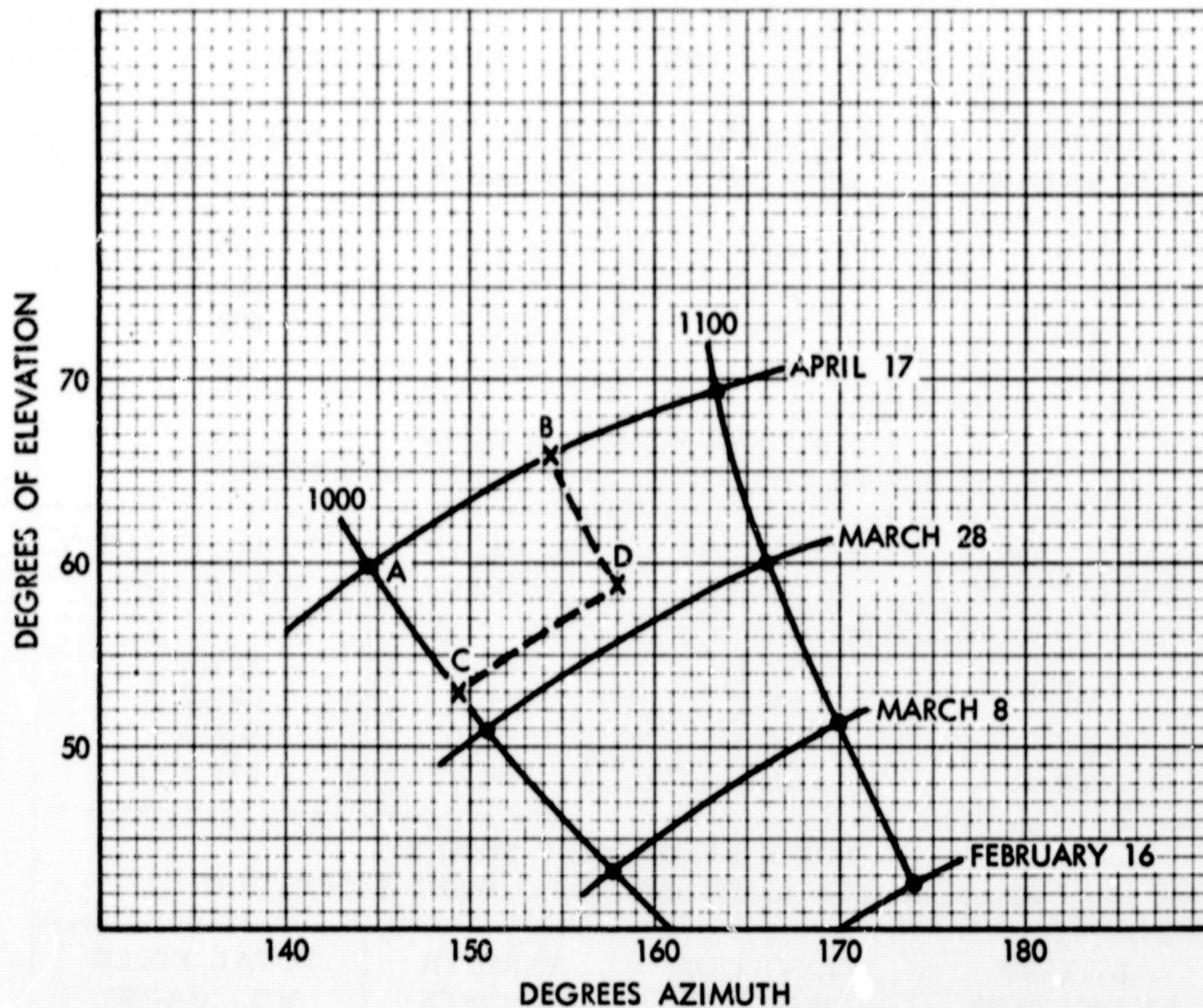
To locate the sun at an integral hour point, but on a day other than one of the days represented by a curve, move a proportional distance between two adjacent day-curves along the line connecting each day-curve for the desired hour. When that point on the line is located, find the angles for the point on the horizontal and vertical scales. Figure 1 illustrates interpolation as explained here.

The azimuth and elevation of the magnetic field are shown on each of the graphs. Table I gives the directions of the magnetic fields of the three launch sites, at different heights.

DETERMINING THE LAUNCH WINDOW

Two conditions should be observed in choosing the time and the direction of launch which are compatible with the use of solar and magnetic sensors.

1. The angle between the direction of the sun and the longitudinal, or Z, axis of the rocket, should be great enough that the sun will be within the field of view of the side-looking solar sensor.
2. The angle between the direction of the sun, and that of the magnetic vector, should also be of sufficient magnitude to produce a well-defined intersection in the pattern indicating the angles of the sun sensor and of the magnetic sensor. This will allow an accurate determination of the attitude of the rocket.



POINT		AZIMUTH	ELEVATION
A	= SUN LOCATION AT 1000 ON APRIL 17	144.3	59.9
B	= SUN LOCATION AT 1033 ON APRIL 17	154.3	66.2
C	= SUN LOCATION AT 1000 ON APRIL 5	149.4	53.2
D	= SUN LOCATION AT 1033 ON APRIL 5	158	58.7

Figure 1. Interpolation on Graphs

TABLE I
MAGNETIC ELEVATION ANGLES (1970)

WALLOPS ISLAND, VIRGINIA 37.8° NORTH LATITUDE, 75.5° WEST LONGITUDE			
ALTITUDE KILOMETERS	ELEVATION DEGREES	AZIMUTH DEGREES	TOTAL FIELD MILLIGAUSS
0	69.7	171.9	556.4
100	69.6	172.1	528.4
200	69.5	172.3	502.4
300	69.4	172.5	478.0
FORT CHURCHILL, CANADA 58.75° NORTH LATITUDE, 94.0° WEST LONGITUDE			
ALTITUDE KILOMETERS	ELEVATION DEGREES	AZIMUTH DEGREES	TOTAL FIELD MILLIGAUSS
0	83.4	184.1	615.0
100	83.2	184.4	585.2
200	83.0	184.5	557.3
300	82.8	184.7	531.2
WHITE SANDS, NEW MEXICO 32.38° NORTH LATITUDE, 106.5° WEST LONGITUDE			
ALTITUDE KILOMETERS	ELEVATION DEGREES	AZIMUTH DEGREES	TOTAL FIELD MILLIGAUSS
0	60.5	191.8	520.7
100	60.6	191.7	494.9
200	60.6	191.6	470.7
300	60.6	191.5	448.2

NOTE: The South-Seeking Direction, or Tail of the vector, is shown, since it has a positive elevation angle.

The time of day of the launch is under the control of the experimenters, unless the time is dictated by the requirements of the experiment, or by range scheduling problems. Any choice of launch azimuth angles is severely limited by range safety requirements, but the launch azimuth may usually be varied over a small angle. Consequently, it is usually possible to sufficiently change either the launch time, or the launch angle, so that the relationship between the direction of launch and the direction of the sun will ensure adequate performance of the solar and magnetic sensors.

DERIVATION OF GRAPH COORDINATES

THEORY

The computations involved in compiling the tables of coordinates are, essentially those of the science of navigation. This science enables a traveler to determine his location on the surface of the earth by observation of the position of certain celestial bodies, at a precise time. There are two publications which are usually used to interpret the data obtained by such observations:

1. The Air Almanac (Reference 1), gives the directions of the sun, and a number of other celestial bodies, from the center of the earth, as a function of time, and expressed in terms of a set of universal coordinates.
2. American Practical Navigator (Reference 2) is a reference work on spherical trigonometry as it relates to terrestrial navigation. Use of the methods contained in Bowditch translates the direction of the sun, from the coordinates of the Air Almanac, to coordinates expressed with respect to a specific location on the earth's surface.

DETERMINING THE COORDINATES

Coordinates for the graphs of Figures 1 through 6 were obtained by solving two spherical trigonometrical equations taken from Bowditch pages 28 and 31. These two equations were chosen because they were considered especially suited to computer methods. For the angle of elevation,

$$\sin E = \sin L \sin D + \cos L \cos D \cos T, \quad [1]$$

and for the azimuth angle,

$$\cos A = \frac{\sin(D-L) \cos^2 \frac{T}{2} + \sin(D+L) \sin^2 \frac{T}{2}}{\cos E} \quad [2]$$

E = Angle of elevation (-90° to $+90^\circ$), degrees above and below the horizon.

A = Angle of azimuth (0° to 360°), measured clockwise from north.

D = Declination of the sun, 90 degrees north(+) to 90 degrees south(-) of the equator.

L = Latitude of the site, 90 degrees north(+) to 90 degrees south(-), referenced to the equator.

T = Local hour angle of the sun, 180 degrees east(+) to 180 degrees west(-), referenced to the launch site.

Latitude and longitude of each of the three sites are contained in Table I.

Declination and Greenwich hour angle of the sun are obtained from the Air Almanac.

The local hour angle is found by algebraically adding the Greenwich hour angle to the longitude of the site.

COMPUTER PROGRAM. Figure 2 illustrates a computer program to take the two site coordinates and the two available solar coordinates as inputs, and give the desired outputs. It is written in A Programming Language (APL), the language of the APL/360 computer system (Reference 3).

The program defines a function which, when provided with numerical values for each of the parameters: latitude and longitude of the site, and declination and Greenwich hour angle of the sun, will give numerical values for the angles of elevation and azimuth of the sun.

EXPLANATION OF THE PROGRAM. Steps 1 through 8 of the program illustrated in Figure 2 are for the assigning of numerical values to the four variables.

Steps 9 through 11 convert degrees to radians.

Steps 12 through 14 compute the local hour angle in radians.

Steps 15 through 17 solve equation 1, and convert the answer to degrees, with the label of ALT.

Steps 18 through 22 solve equation 2. Its answer, in degrees, is labeled AZT.

Steps 23 and 24 give the answers, in elevation and azimuth angles.

USE OF PROGRAM. The program can be stored, using the key word, SUN. Figure 3 contains an example of how the program can be used to solve the two equations for each pair of coordinates for the graphs.

ERRORS CAUSED BY LEAP YEAR CYCLE

Because the length of a year is not an integral multiple of the length of a day, the leap year system was developed to keep the long-term time relationship between the day and the year nearly constant. However, over a four-year period, there is a slight variation of the time relationship between any given day and the solar phenomena, the elevation and azimuth angles, but the greatest variation, that of the elevation is not considered great enough to be significant. Table II shows some typical five-year comparisons for a specific day and hour. The maximum difference in elevation over the period 1962 through 1966, is found to be 0.29 degrees, or 17.4 minutes.

```

      VSUN[ ] V
V SUN
[1]  ' ENTER DECLINATION -90 TO 90 '
[2]  DEC←[ ]
[3]  ' ENTER GREENWICH HOUR ANGLE 0 TO 360 '
[4]  GHA←[ ]
[5]  ' ENTER LONGITUDE -180 TO 180 '
[6]  LON←[ ]
[7]  ' ENTER LATITUDE -90 TO 90 '
[8]  LAT←[ ]
[9]  RAD←57.2957795
[10] D←DEC÷RAD
[11] L←LAT÷RAD
[12] TTT←GHA+LON
[13] LHA←(TTT×(TTT≤180))+(-360+TTT)×(TTT>180)
[14] T←LHA÷RAD
[15] H←((20D)×(20L)×(20T))+(10D)×10L
[16] A←-10H
[17] ALT←A×RAD
[18] ZS←(((10(D-L))×((20(T÷2))×2))+((10(D+L))×((10(T÷2))×2)))÷20A
[19] Z←-20ZS
[20] AM←RAD×Z
[21] AZH←360-AM
[22] AZT←(((T<0)×AM)+((T≥0)×AZH))
[23] ' ELEVATION ' ;ALT
[24] ' AZIMUTH ' ;AZT
V

```

Figure 2. APL/360 Program for Computing Elevation and Azimuth of Sun

```

      SUN
ENTER DECLINATION -90 TO 90
[]:
      -21.8
ENTER GREENWICH HOUR ANGLE 0 TO 360
[]:
      178
ENTER LONGITUDE -180 TO 180
[]:
      -94
ENTER LATITUDE -90 TO 90
[]:
      58.8
ELEVATION -15.51
AZIMUTH 253.4

```

Figure 3. Example of Use of Program Shown in Figure 2

TABLE II
COMPARISONS OF SOLAR COORDINATES, SHOWING
VARIATIONS DURING A LEAP YEAR CYCLE*

DAY	YEAR	GREENWICH HOUR ANGLE (DEGREES)	LOCAL HOUR ANGLE DEGREES	ELEVATION DEGREES	AZIMUTH DEGREES
Jan. 11	1962	88.00	-6.00	9.247	174.4
Jan. 11	1963	88.03	-5.97	9.219	174.4
Jan. 11	1964	88.07	-5.93	9.181	174.4
Jan. 11	1965	87.97	-6.03	9.295	174.3
Jan. 11	1966	88.00	-6.00	9.267	174.4
April 1	1962	89.01	-4.99	35.63	173.9
April 1	1963	89.00	-5.00	35.54	173.9
April 1	1964	89.05	-4.95	35.83	173.9
April 1	1965	89.03	-4.97	35.73	173.9
April 1	1966	89.01	-4.99	35.63	173.9
July 10	1962	88.70	-5.30	53.23	171.8
July 10	1963	88.70	-5.30	53.38	171.8
July 10	1964	88.67	-5.33	53.17	171.7
July 10	1965	88.68	-5.32	53.20	171.8
July 10	1966	88.68	-5.32	53.23	171.8
Oct. 18	1962	93.70	-0.30	21.57	179.7
Oct. 18	1963	93.68	-0.32	21.65	179.7
Oct. 18	1964	93.72	-0.28	21.37	179.7
Oct. 18	1965	93.70	-0.30	21.47	179.7
Oct. 18	1966	93.70	-0.30	21.55	179.7

*The time of day for each entry is 1800, or 6:00 P.M. local time.

REFERENCES

1. The Air Almanac, in the United States, issued by the Nautical Almanac Office, United States Naval Observatory, and for sale by the United States Government Printing Office. The 1969 edition is used.
2. American Practical Navigator, 1962, corrected reprint, originally by Nathaniel Bowditch, L. L. D., published by the U. S. Navy Hydrographic Office, and for sale by the United States Government Printing Office.
3. Iverson, K. E.: A Programming Language, Wiley, 1962.

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1. F. Mariani and E. E. Hoover: "A Concise Tabulation of Solar Zenith Angles for use in Upper Atmospheric Research," GSFC Report X-615-64-58, March, 1964.
2. A. D. Falkoff and K. E. Iverson: "APL/360 User's Manual," 1968, International Business Machines Corporation.
3. "APL/360 Primer," 1969, International Business Machines Corporation.

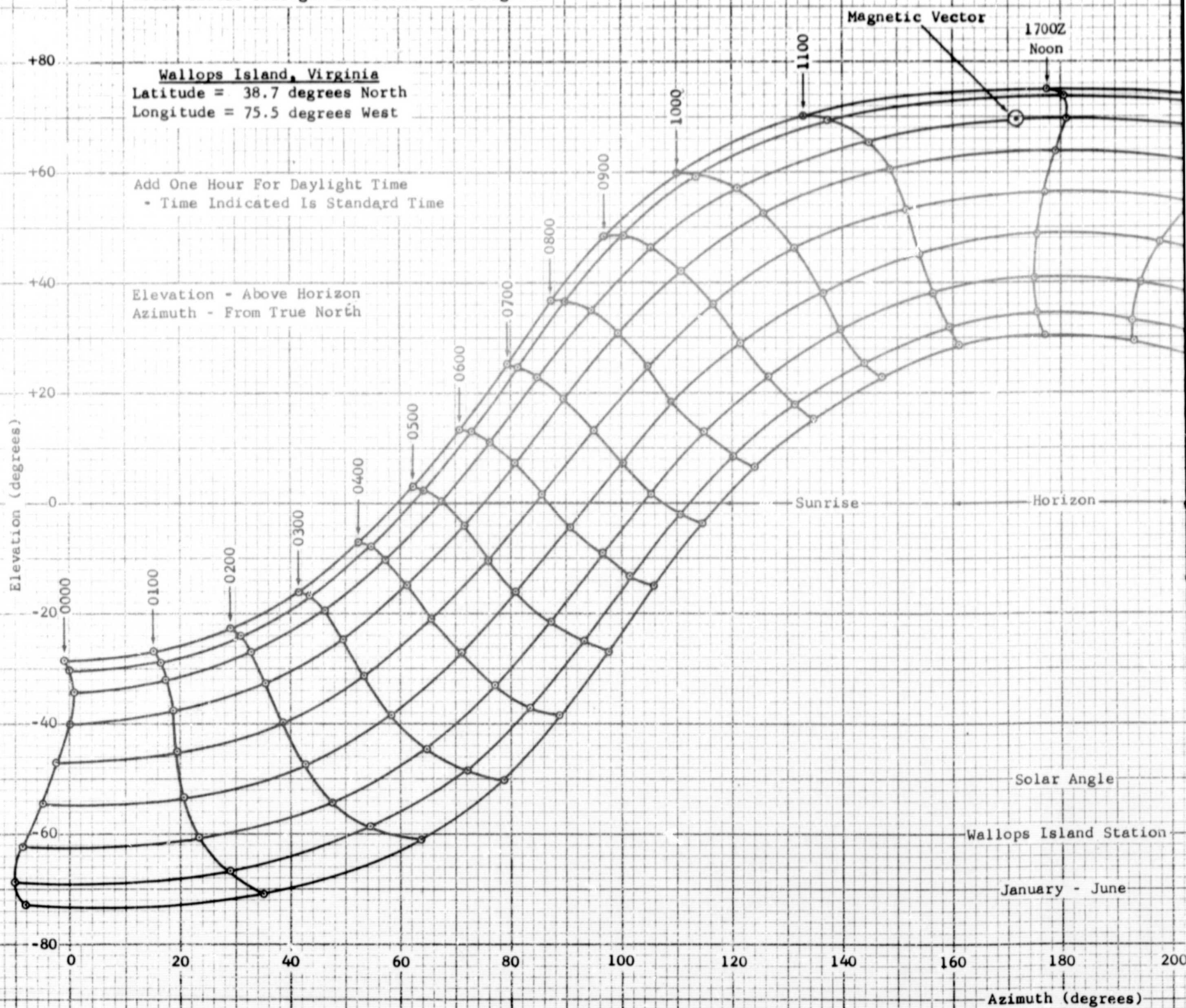
APPENDIX A

Civil Twilight Elevation = -6 degrees
Astronomical Twilight Elevation = -12 degrees

Wallops Island, Virginia
Latitude = 38.7 degrees North
Longitude = 75.5 degrees West

Add One Hour For Daylight Time
• Time Indicated Is Standard Time

Elevation - Above Horizon
Azimuth - From True North



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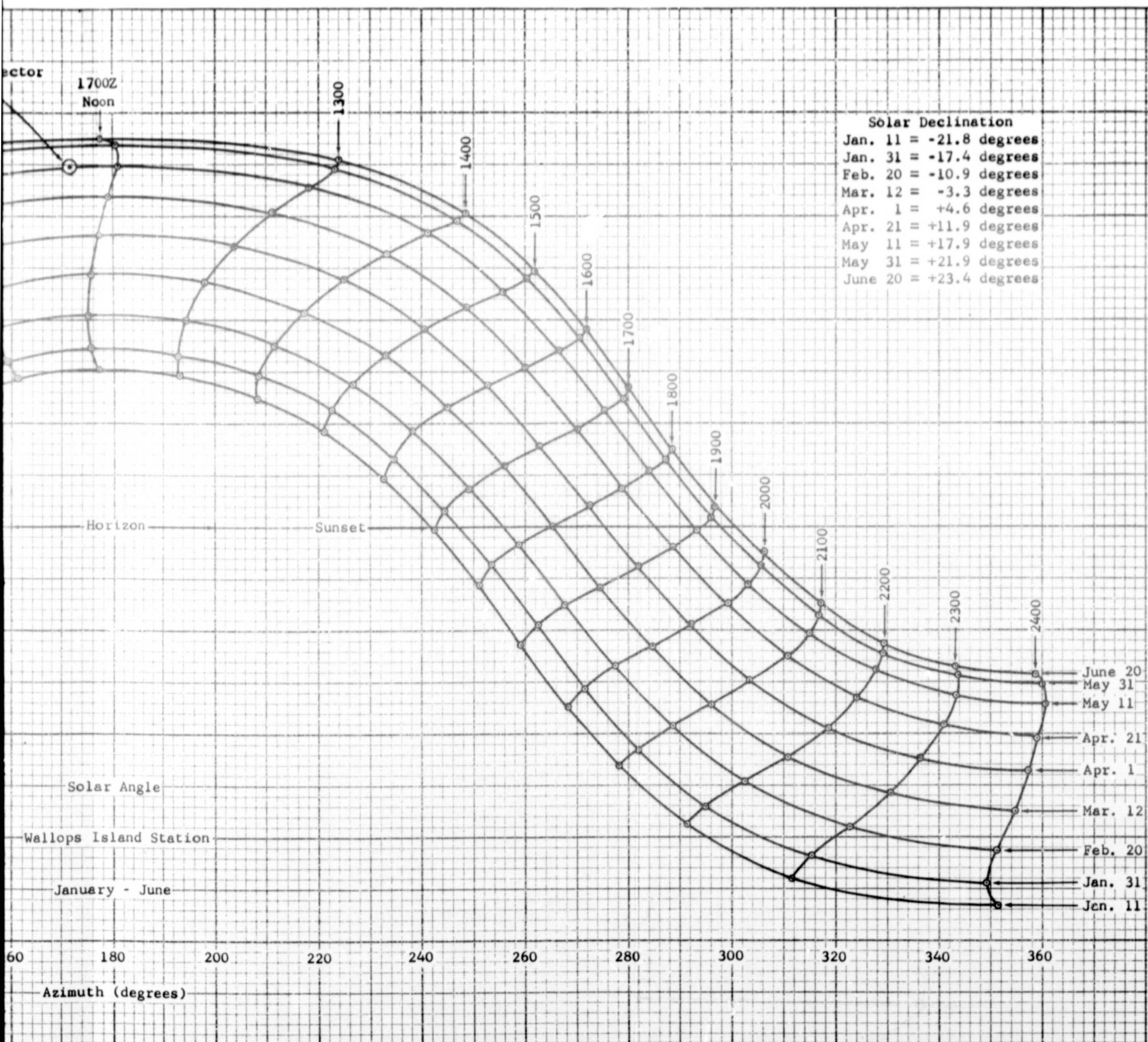


Figure A-1. Positions of Sun, January-June, Wallops Island Station

A-3

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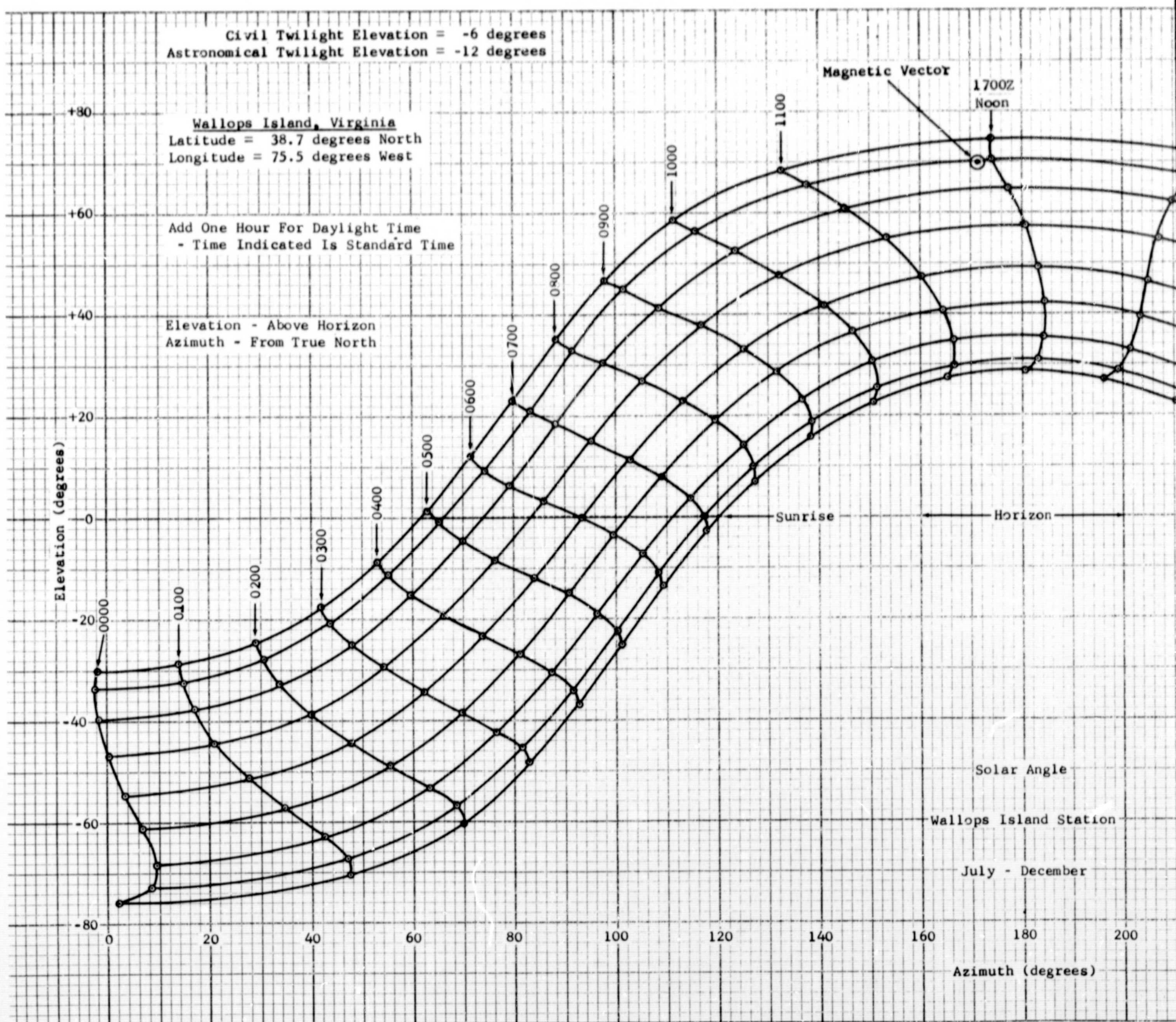
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Civil Twilight Elevation = -6 degrees
Astronomical Twilight Elevation = -12 degrees

Wallops Island, Virginia
Latitude = 38.7 degrees North
Longitude = 75.5 degrees West

Add One Hour For Daylight Time
- Time Indicated Is Standard Time

Elevation - Above Horizon
Azimuth - From True North



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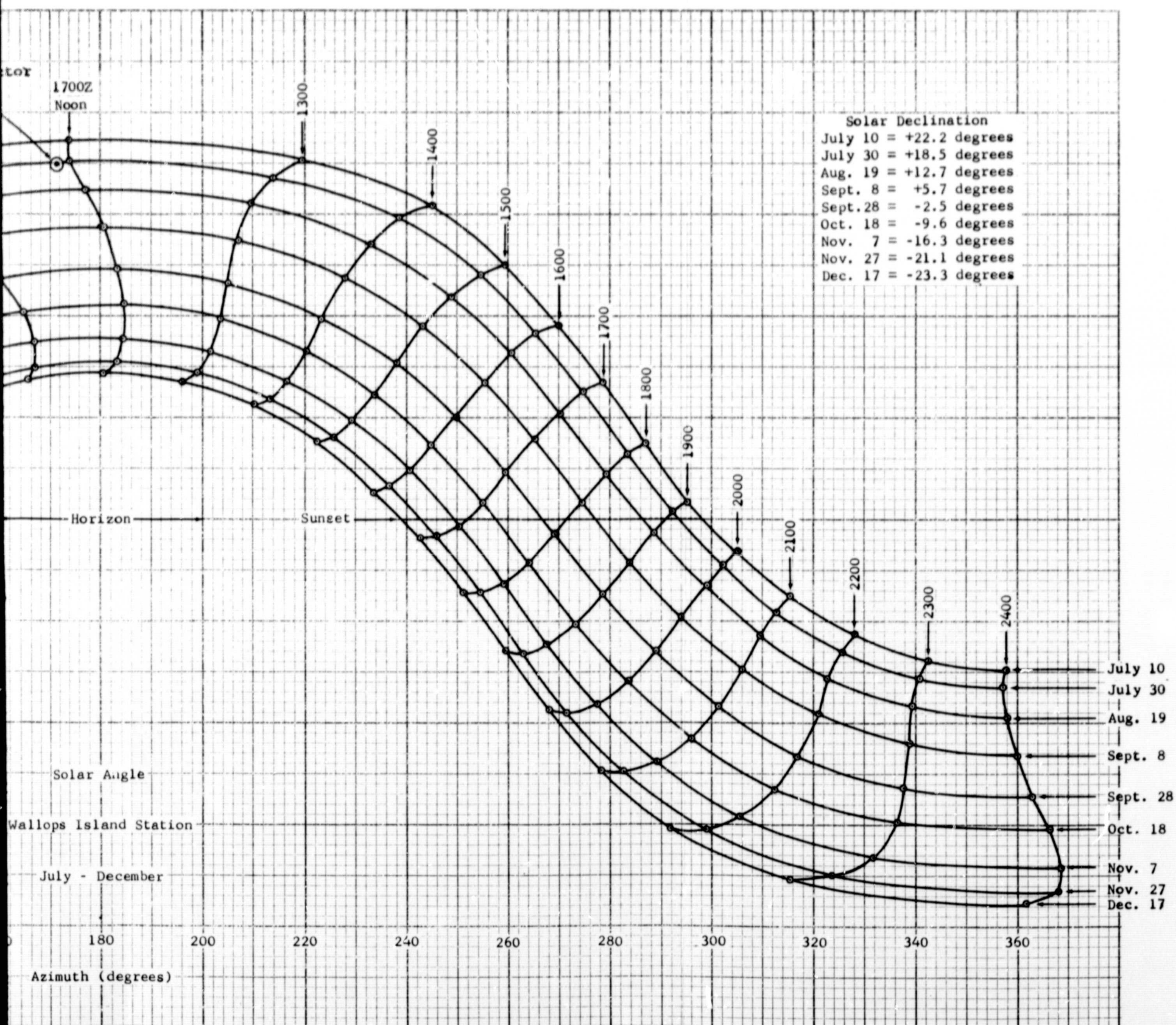


Figure A-2. Positions of Sun, July-December, Wallops Island Station

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Civil Twilight Elevation = -6 degrees
Astronomical Twilight Elevation = -12 degrees

Fort Churchill, Canada
Latitude = 58.8 degrees North
Longitude = 94.0 degrees West

Add One Hour For Daylight Time
- Time Indicated Is Standard Time

Elevation - Above Horizon
Azimuth - From True North

Magnetic Vector

1800Z
Noon

1300

0900

1000

1100

0800

0700

0600

0500

0400

0300

0200

0100

0000

Sunrise

Horizon

Sunset

Solar Angle

Ft. Churchill Station

January - June

Azimuth (degrees)

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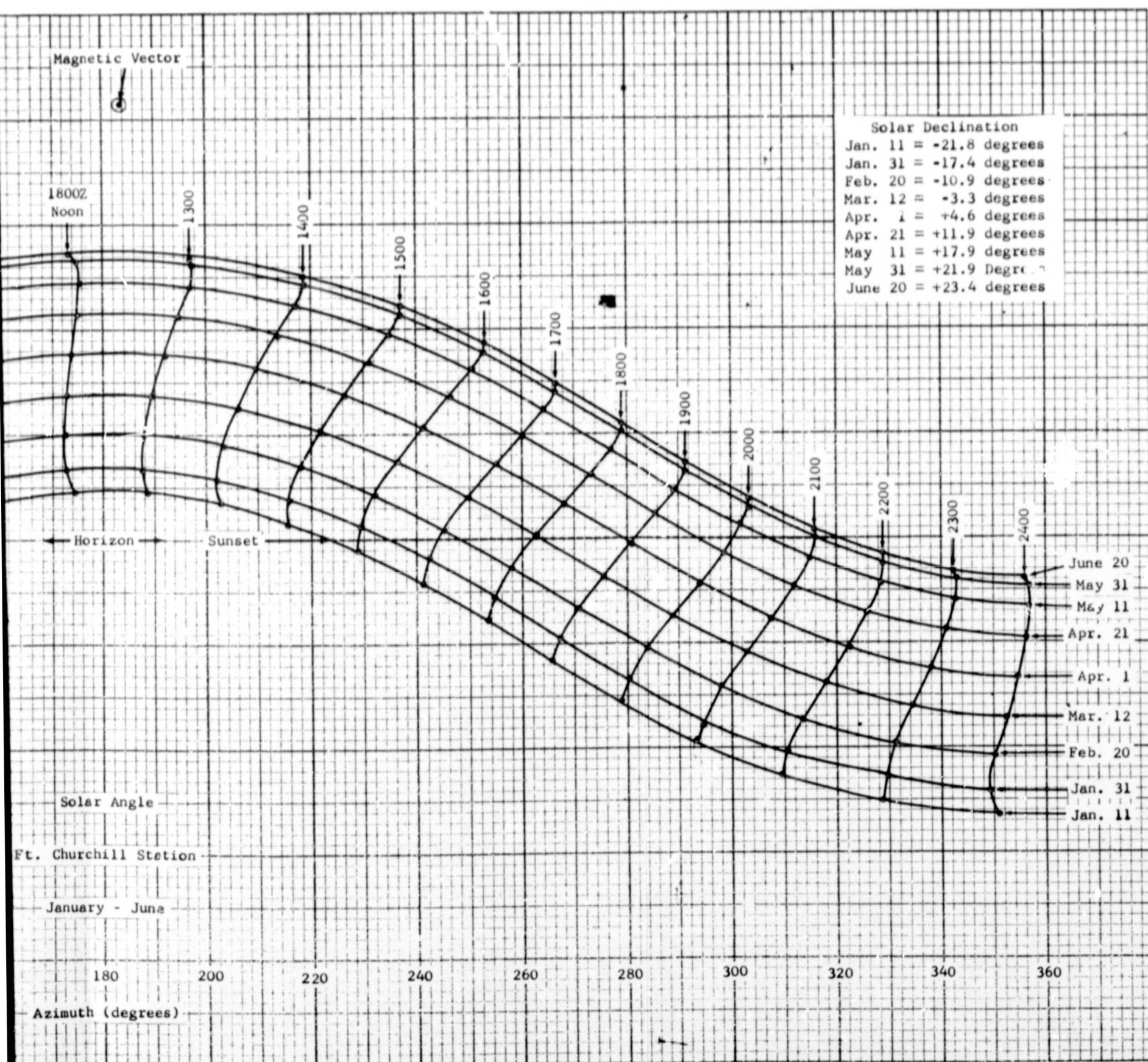


Figure A-3. Positions of Sun, January-June, Fort Churchill Station

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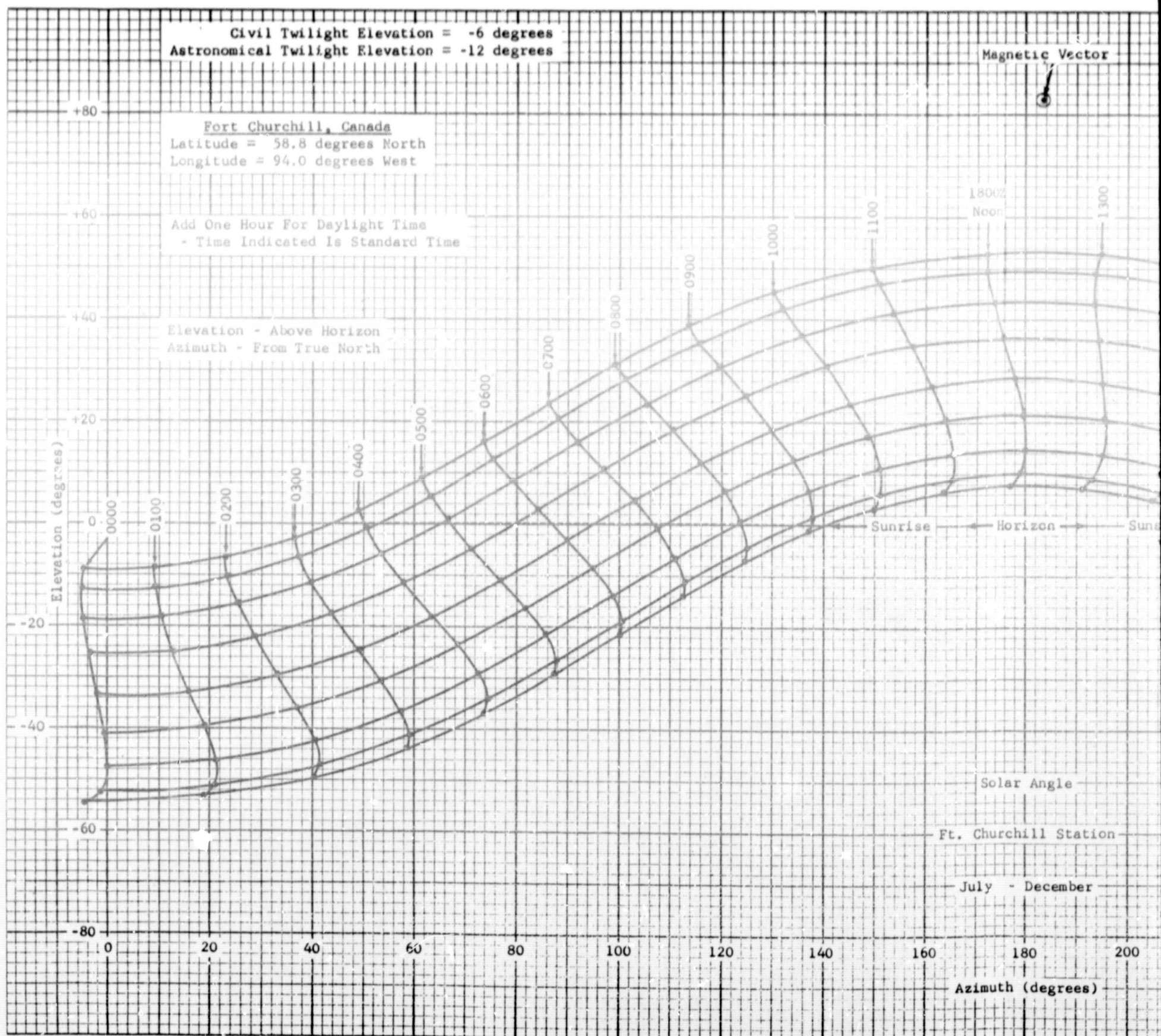
Civil Twilight Elevation = -6 degrees
Astronomical Twilight Elevation = -12 degrees

Magnetic Vector

Fort Churchill, Canada
Latitude = 58.8 degrees North
Longitude = 94.0 degrees West

Add One Hour For Daylight Time
- Time Indicated Is Standard Time

Elevation - Above Horizon
Azimuth - From True North



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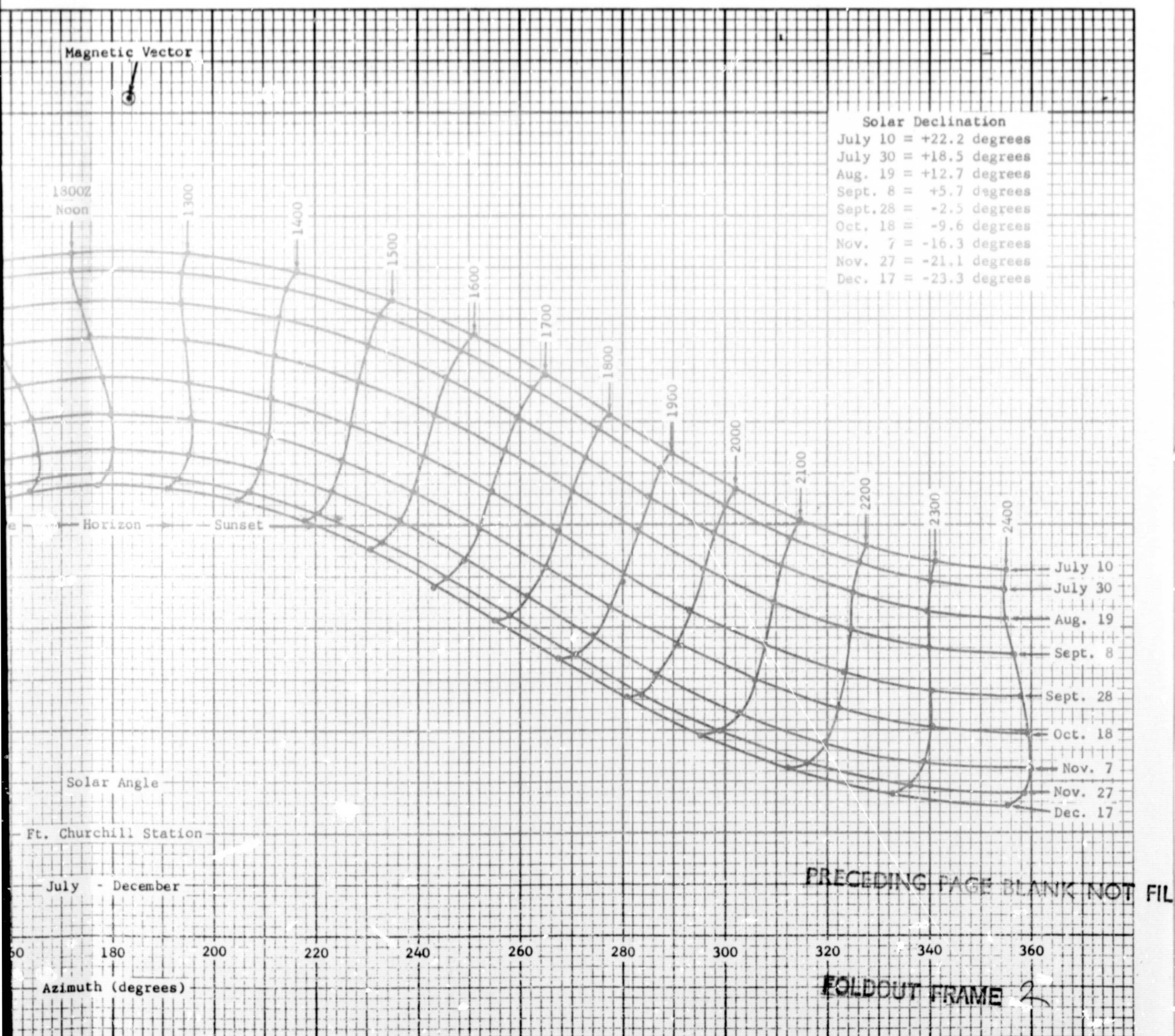


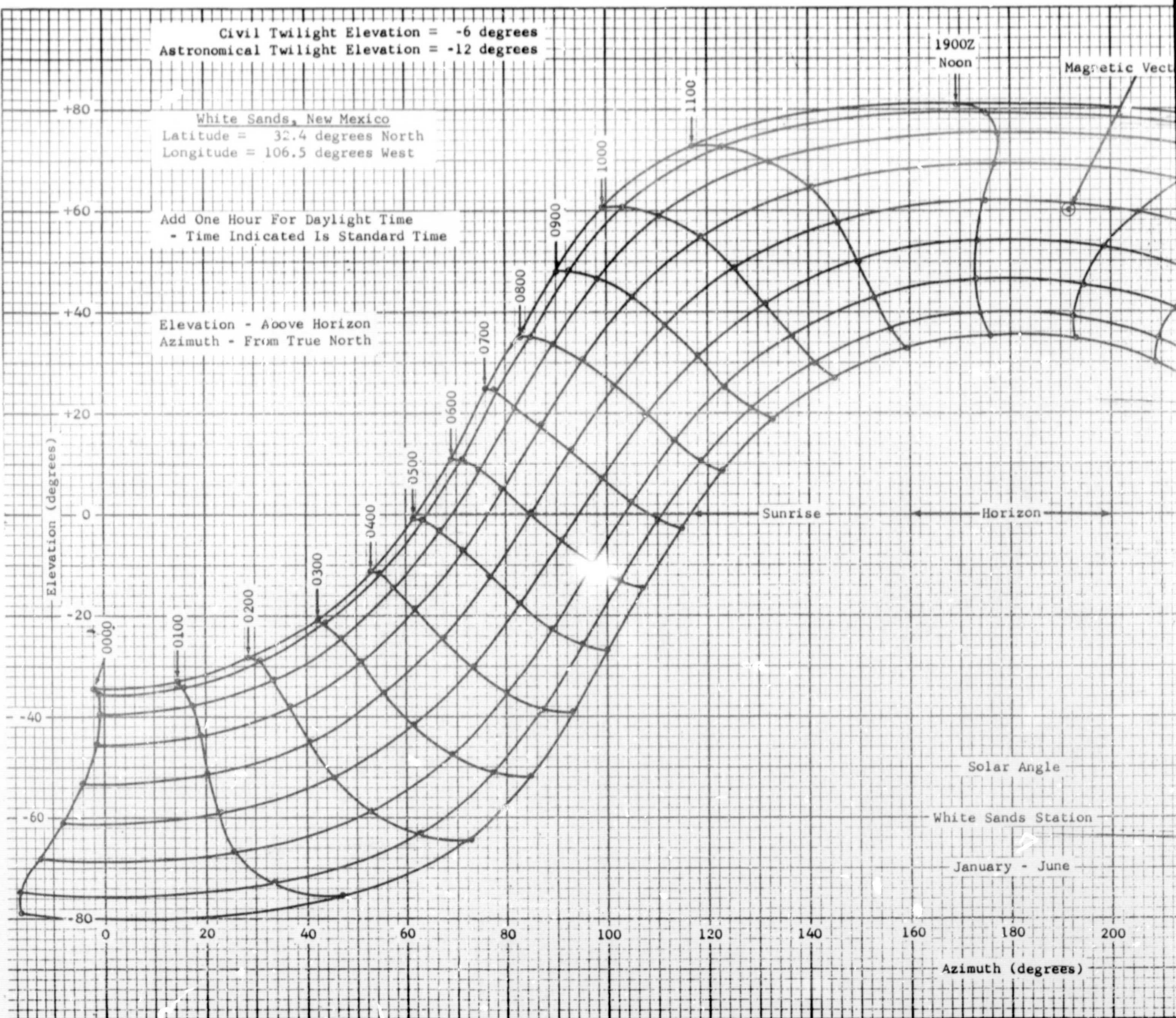
Figure A-4. Positions of Sun, July-December, Fort Churchill Station

Civil Twilight Elevation = -6 degrees
Astronomical Twilight Elevation = -12 degrees

White Sands, New Mexico
Latitude = 32.4 degrees North
Longitude = 106.5 degrees West

Add One Hour For Daylight Time
- Time Indicated Is Standard Time

Elevation - Above Horizon
Azimuth - From True North



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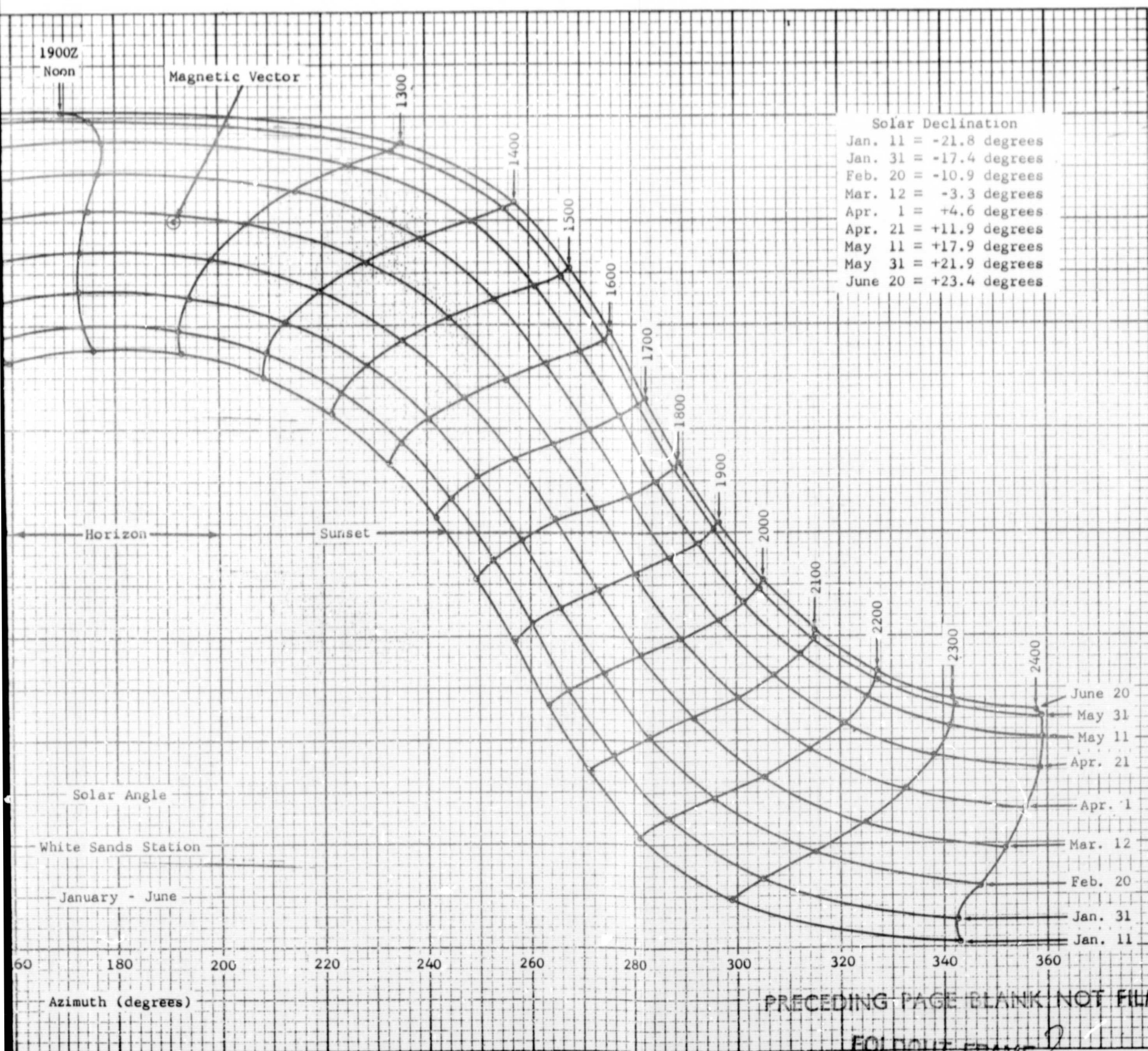
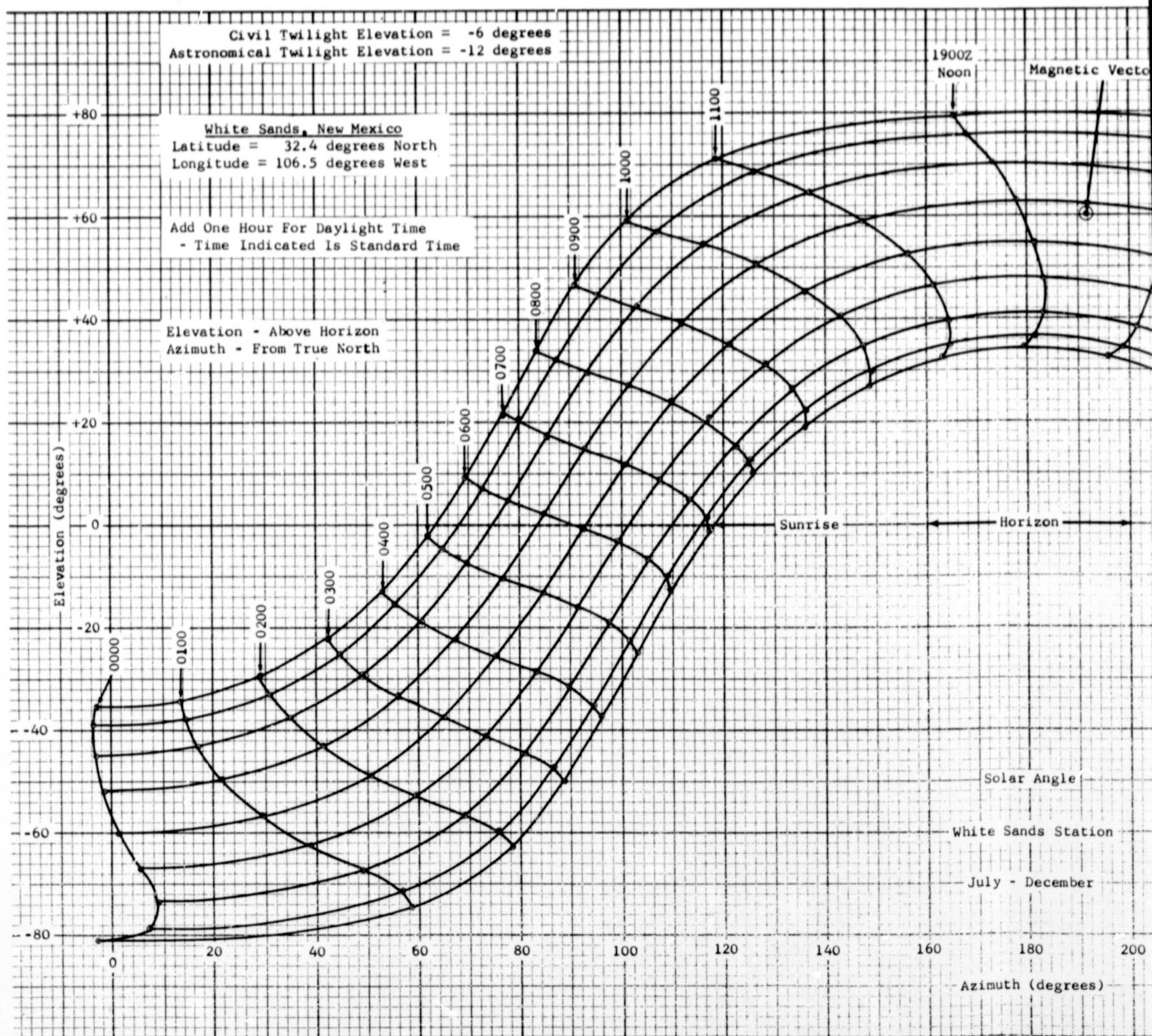


Figure A-5. Positions of Sun, January-June, White Sands Station



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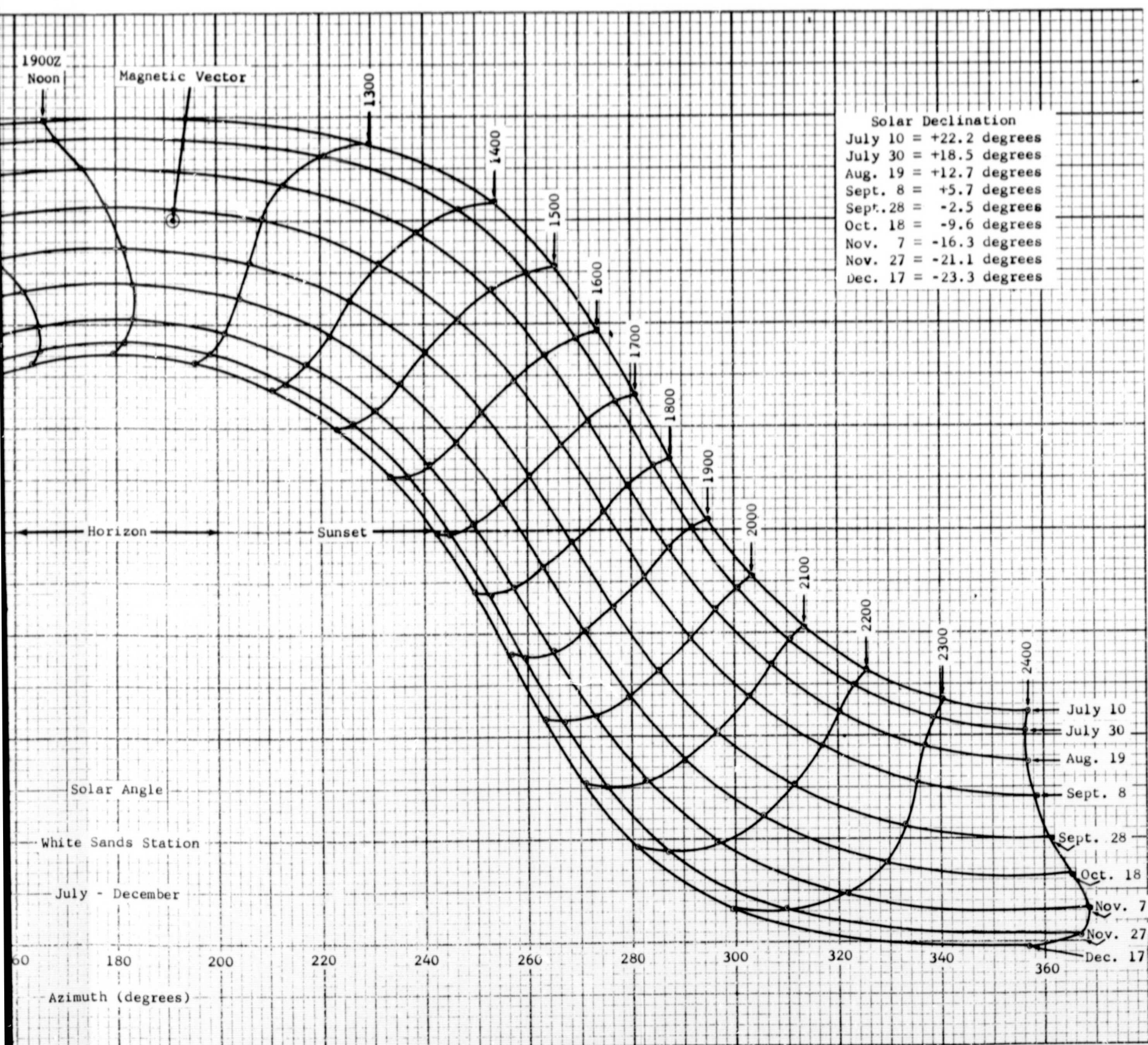


Figure A-6. Positions of Sun, July-January, White Sands Station

A-13

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